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WATER ...

and the Land

Facts About Our Water Problem

By
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WATER AND THE LAND

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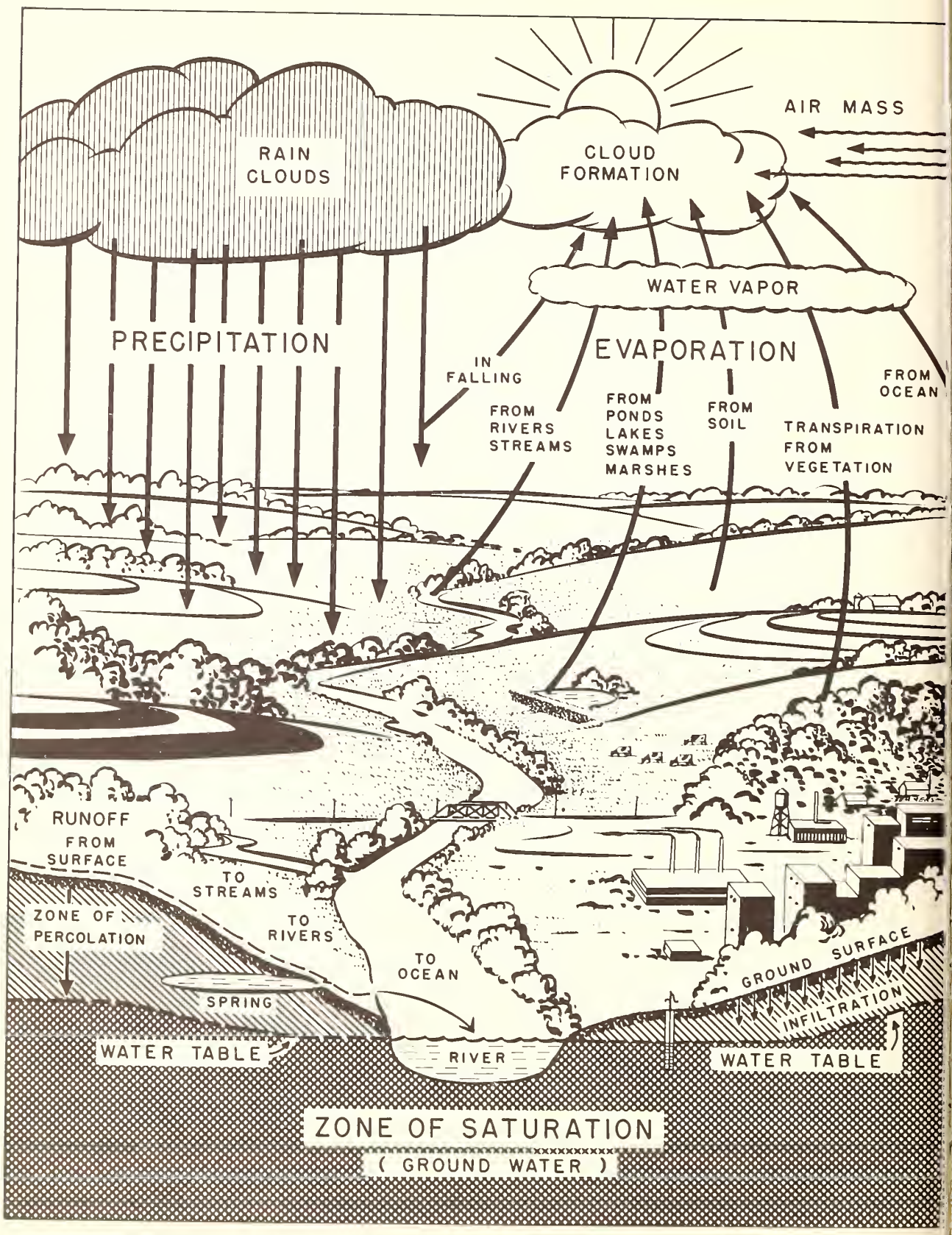

AIR MASS
RAIN CLOUDS
CLOUD FORMATION
WATER VAPOR
PRECIPITATION
EVAPORATION
IN FALLING
FROM RIVERS STREAMS
FROM PONDS LAKES SWAMPS MARSHES
FROM SOIL
TRANSPIRATION FROM VEGETATION
FROM OCEAN
RUNOFF FROM SURFACE
TO STREAMS
TO RIVERS
TO OCEAN
ZONE OF PERCOLATION
SPRING
WATER TABLE
RIVER
GROUND SURFACE
INFILTRATION
WATER TABLE
ZONE OF SATURATION
(GROUND WATER)

THE WATER PROBLEM

The water problem is not one, but many.

There is no national water shortage, but many communities must ration their water supplies.

Every year floods strike scores of communities with disaster. Yet hundreds of arid-land communities would greet a cloudburst as a godsend.

Drought is a recurring hazard in the Great Plains while drainage is a common problem in the Coastal Plain.

Nearly everywhere there's a water problem--too little or too much, too soon or too late. But each is a local problem, understandable only against the background of local resources, economic development, and needs.

The national aspect of the water problem is the need to conserve and manage the available water in each community to best serve the longtime needs of its people.

To understand the problem we need to know some basic facts about water and its use and conservation.

THE WATER SUPPLY

There is just so much water. Except for negligible amounts newly created or destroyed by chemical changes, the earth's water supply remains constant.

But that supply is always on the move. From clouds in the sky to land and ocean, and back to the sky again--it goes round and round in the water cycle, and we use the same water again and again.

Vagaries of its movement through the cycle--uneven distribution and irregular timing--give rise to most problems of local water shortage or excess.

U.S. Weather Bureau records show that average annual precipitation (rain, hail, snow, sleet) in the United States if spread evenly over the surface would be about 30 inches. This amounts to about 4,300 billion gallons a day. That is our total water supply.

U.S. Geological Survey data show that total streamflow derived from surface runoff and ground water amounts to about 8.5 inches a year, or about 1,200 billion gallons a day on the average (13).[1] That is the potential sustained supply for direct human use in homes, industries, irrigation, recreation, etc. It is more than four times the average daily use now, about two times the predicted requirements in 1980. Of this total streamflow (1,200 billion gallons a day) 270 billion gallons a day was withdrawn for human use in 1960 and 61 billion gallons a day was consumed. Much that was withdrawn but not consumed was deteriorated in quality.

The difference between precipitation and streamflow is the amount returned to the atmosphere as vapor by evaporation and transpiration or lost to deep underground flow. That is 21.5 inches a year or 3,100 billion gallons a day, roughly 70 percent of the total water supply. It includes the water used to grow crops, pastures, forests, and all other vegetation that covers land.

The water cycle

Precipitation is the source of our water supply.

As water falls upon the earth, part evaporates and part enters soil. If it falls faster than the soil can take it in, the excess runs off over the surface into streams and eventually to lakes or the sea.

Of the water that enters the ground, most is held in soil and is used by plants or is evaporated. In either event, it returns to the atmosphere as vapor.

Part passes downward to the ground-water reservoir. When storage spaces are filled, the excess moves laterally and comes to the surface as springs or seeps or augments streamflow.

Thus, in time, practically all water not evaporated from inland surfaces reaches the oceans. Here it passes again into the atmosphere, is carried inland by winds, forms clouds, and falls as rain, snow, hail, or sleet. This completes the water cycle.

Water and land

What happens to the 4,300 billion gallons a day of precipitation that must replenish our water supply is greatly influenced by the management of watersheds. Whether water enters the ground or runs off overland depends largely upon the nature and condition of the soil and its vegetative cover.

Water, therefore, is essentially an agricultural resource. The farmers and ranchers who control our farmland, rangeland, and woodland also control to an important degree the movement of water that falls on their land.

USE OF WATER BY PLANTS

Plants take their share of water as it comes to us in the water cycle even before man and animals have an opportunity to use it for drinking.

Water is essential to photosynthesis, by which plants make food that supports all animal life. This is one of the most important uses of water.

About 70 percent of the water reaching the land surface, or 3,100 billion gallons daily, is transpired in growth of plants or evaporated directly from soil and other surfaces (38). How much of this combined requirement, called "evapotranspiration," actually passes through plants is not known.

But plant growth consumes tremendous amounts of water. A growing tree is at least 50 percent water. Succulent plants like cabbage or lettuce are more than 80 percent water.

The amount of water used by a plant varies widely with kind of plant and variations in weather, availability of moisture, and other conditions. At Manhattan, Kans., in one study, single plants of

[1] Numbers in parentheses refer to Literature Cited, p. 16.

different species used amounts of water ranging from 13 to 140 gallons each during the growing season (14, p. 412), as follows:

	Gallons
Corn	54
Cowpea	13
Potato (1 hill)	25
Sunflower	130
Ragweed, giant	140
Tomato (pruned to 1 stem)	34
Winter wheat	25

At 54 gallons per plant, 1 acre of corn at ordinary spacing would transpire 11 inches of water in a season. Additional water would be evaporated directly from the soil. Total water requirement for irrigating corn ranges from 19 to 29 inches in different parts of the country (4).

Another measure of water requirement of plants is pounds of water transpired per pound of dry matter produced. Table 1 gives examples from studies at Akron, Colo., for the 7 years 1911-17 (20).

Available moisture limits plant growth in many parts of United States. Successful farming and ranching depend upon catching and holding in soil as much water as possible for crop and forage production.

TABLE 1.--Water transpired per pound of dry matter produced, 1911-17, Akron, Colorado

Kind of plant	Pounds of water used--		
	Per pound of dry matter except roots		Per pound of grain
	Low High	Average	Average
	Pounds	Pounds	Pounds
Crops:			
Alfalfa	482-1,168	844	
Clover, crimson	490- 805	636	1,583
Corn	212- 516	349	1,405
Cotton	443- 657	568	
Cowpeas	413- 767	569	1,632
Sorghum, grain	282- 356	304	868
Sweet clover	574- 913	731	
Wheat	369- 869	557	1,872
Grasses:			
Brome, smooth	752-1,192	977	
Buffalograss	258- 346	296	
Grama, blue	290- 389	338	
Wheatgrass, western	797-1,263	1,035	
Weeds:			
Buffalobur	413- 654	536	
Cocklebur	320- 506	415	
Gumweed	450- 714	585	

WATER FOR HUMAN USE

In United States we face a number of serious water problems. Some are regional and caused by climatic conditions that cannot be changed or depended on. Others are the result of overuse or inefficient use of water supplies that could be adequate if managed and used economically. Planned water management is an urgent need that should be attended to in the very near future.

While the potential supply of water after evapotranspiration remains constant, needs for human use pyramid with growing population. Expanding industry and rising standards of living require more water per person to satisfy the American way of life.

From 1900 to 1950, while our population doubled, total water use, other than for power, increased fourfold (18).

Average daily use for all purposes increased from 600 gallons per capita in 1900 to 1,100 gallons in 1950 (18). By 1960 per capita water use had increased to 1,500 gallons (13).

The Senate Select Committee on National Water Resources estimated that the country will be using nearly 2,300 gallons of water a day for every man, woman, and child by 1980, and 2,700 gallons a day by 2000 (37).

Table 2 shows the trend in water use by estimated withdrawals for major uses in billions of gallons per day (bgd).

Withdrawal and consumption

Not all uses of water reduce the supply. Some, such as recreation and navigation, do not even require that water be taken out of lakes, streams, or other storage.

Figures on amounts of water used for different purposes, such as the foregoing, are for "withdrawals." Some water is withdrawn, used, and returned to source only to be withdrawn again. Some water is recirculated and used several times in the same plant before it is returned to source. Each time water is taken from a natural source it is counted in withdrawals, on the assumption that duplicate withdrawals are offset by circulation.

Important withdrawal uses are (1) public supply (municipal); (2) agricultural, including rural, domestic, and irrigation; (3) industrial; and (4) water power. Nonwithdrawal uses include navigation, recreation, waste disposal, and wildlife conservation.

Water is "consumed" when it is incorporated into a product or is evaporated. Most uses are only partly "consumptive." It is estimated that less than a fourth of withdrawn water (table 3) is consumed.

TABLE 2.--Trends in water uses

Withdrawal uses	Withdrawn			Projections			
	1950[1]	1955[1]	1960[1]	1980[2]	Percent of 1960	2000[2]	Percent of 1960
	Bgd	Bgd	Bgd	Bgd	Percent	Bgd	Percent
Public supplies (municipal)	14	17	21	29	138	42	200
Total agriculture[3]	[4] 82.6	113.6	113.6	167	148	184	162
Rural (domestic and livestock)	3.6	3.6	3.6	[5] 6	167	[5] 7	195
Irrigation (without conveyance losses)	79	81	84	[6] 102	121	[6] 123	148
Irrigation (including conveyance losses)	--	110	110	[6] 161	146	[6] 177	160
Industry (mining, manufacture, steam-electric power)	77	110	140	363	259	662	472
Totals	[4] [7] 170	[7] 240	[7] 270	559	207	888	337

[1] (13).
[2] (37).
[3] Irrigation plus rural domestic and livestock.
[4] Not including conveyance losses.
[5] Calculated as difference between irrigation (31) and total for agriculture (37).
[6] (31).
[7] Figures rounded to 2 significant digits; total derived from unrounded data does not agree with sum of components after rounding.

TABLE 3.--Consumptive use of water

Water uses	1960 Withdrawn	1960 Consumed		Projections[1] consumptive use	
				1980	2000
	Bgd	Bgd	Percent	Bgd	Bgd
Public supplies	21	3.5	17	3.7	5.5
Rural (livestock and domestic)	3.6	2.8	78		
Irrigation (without conveyance losses)	84	52	62		
Irrigation (including conveyance losses)	110				
Total agriculture[2]	113.6	[3] 54.8		104.5	126.3
Industry	140	3.2	2	11	24.4
Totals	[4] 270.0	[4] 61.0	25	119.2	156.2

[1] (37).
[2] Irrigation, livestock, and rural domestic.
[3] Irrigation plus rural.
[4] Rounded to 2 significant digits; totals derived from unrounded data do not agree with sums of components after rounding.

About 83 percent of municipal water, 98 percent of industrial water, and 60 percent of irrigation water delivered to farms is returned to surface or underground storage. These percentages will be reduced, however, as industry and agriculture improve the efficiency of water use.

Use of water for power is nonconsumptive, except evaporation from storage and steam plants, which can be large.

Most nonwithdrawal uses are also nonconsumptive although there is loss by evaporation from bodies of water provided for these purposes.

Water for cities and towns

Cities and towns are using more water every year. Both the number of people and the per capita water requirements are increasing.

Municipal water systems supplied their customers 14 billion gallons a day in 1950 and 21 billion in 1960 (13).

The U.S. Public Health Service (35) estimated that total water needs of municipalities will reach 29 billion gallons a day by 1980 and 43 billion gallons a day by 2000. These projections, made for the Senate

Select Committee on National Water Resources, indicate that withdrawals from public supplies will increase about 40 percent over the 1960 level by 1980 and be twice as great by the year 2000.

About two-thirds of municipal water comes from streams and lakes, and about one-fourth from ground water (13).

Average per capita use of municipal water has increased from 95 gallons a day in 1900 to 145 gallons in 1950 and 147 gallons in 1954. It is expected to reach 152 gallons per day by 2000 (35).

Per capita use varies widely from one part of the country to another. The Public Health Service found that in 1954 per capita water use from municipal systems was highest in the Great Basin Water Resource Region where on an average people in towns and cities used 246 gallons of water a day. Lowest average per capita use was 116 gallons a day in the Southeast. In between these extremes were widely varying per capita uses for the 20 additional water resource regions and an average of 147 gallons a day for the United States as a whole. Per capita water use from municipal systems is expected to decline by 1980, and be lower by 2000, in half of the country's water resource regions.

About 40 percent of water supplied by municipal systems is used in and about homes; the rest is used by industries and for public services (35). The average electrified home, urban or rural, uses 40 to 60 gallons of water a day (19). In the West and Southwest, heavy use of water for lawn sprinkling and air conditioning increases this figure somewhat.

Municipal water use is largely nonconsumptive. Nationally, about 17 percent of that withdrawn is consumed (table 3), leaving more than four-fifths to be returned to natural sources. However, water discharged as waste by some cities is so badly polluted that it is impractical to reuse it, and it may even seriously lower the quality of the water into which it is discharged (37).

Improvements in standards of living and increased use of water-connected devices account for much of the upward trend in per capita use in the last two decades. Fewer than 300,000 air conditioners were sold in 1946, and 1,075,000 in 1953. In 1958 more than 1,700,000 were produced to meet the demand for new ones. About 2 million washing machines were sold in 1946; 3 million in 1953, and 3,800,000 in 1958 (25).

Water for rural homes and livestock

Water has always been a major item in locating farms and ranches. The pioneer settler cleared his farmstead beside a spring or stream to provide drinking water for his family and livestock. Plainsmen depended upon finding water for a well, and in the far West stockmen feuded over the scattered waterholes.

Rural water comes from private sources. There is no record of the amount used, as there is for municipal systems. Quantity can only be estimated from population figures and average requirements.

On this basis, U.S. Geological Survey estimated that in 1960 about 2 billion gallons a day was used in rural homes and 1.6 by livestock. About 2.8 billion gallons a day was from wells and springs (13).

Rural domestic water needs are figured at 50 gallons a person per day in homes with running water, and 10 gallons per day for those without. In 1954 about 36 million of the 48 million rural people lived in homes with running water.

Livestock water needs are figured at 20 gallons per animal per day for milk cows; 10 gallons for other cattle, horses, and mules; 3 gallons for hogs; 2 gallons for sheep and goats; and 0.04 to 0.06 gallons for poultry (13).

Most rural domestic water is directly consumed for drinking or cooking or by livestock. Waste is usually exposed to evaporation. Use of water in farm and ranch homes, therefore, is largely consumptive. Only about one-fifth is returned to storage or streamflow (tables 2 and 3).

Water for irrigation

Irrigation is the Nation's greatest consumptive use of water although industry exceeds it in volume of withdrawals.

Farmers withdraw for irrigation about 60 percent as much water as industries use, and four times as much as municipalities. About 60 percent of irrigation water, however, is evaporated or transpired by crops (13), whereas industries return 98 percent and municipalities 83 percent of their water to sources from which it can be used again.

As a result, irrigation accounts for the disappearance of several times as much water as all other uses combined.

The National Inventory of Soil and Water Conservation Needs reported nearly 37 million acres of irrigated land in the 17 Western States in 1958 (27).

The extent of irrigation undoubtedly will increase in the years ahead. The Department of Agriculture (USDA) estimated that 36.7 million acres would be irrigated by 1980 and 55.5 million acres by 2000, to meet the expected demands for farm products. The Conservation Needs Inventory indicated that there might be even more rapid expansion of irrigation in the West, possibly to 45 million acres by 1975.

Irrigation is spreading in the humid East, also. In 1960, 1.8 million acres in more than 39,000 farms was irrigated in 30 eastern States, compared to 1/2 million acres in 1944 (26). For the 30 States, the largest single irrigated crop in 1960 was rice, with 424,657 acres mostly in Arkansas and Mississippi.

Unfortunately, prevailing methods of irrigation require much more water to be withdrawn than is actually needed by crops. Part of the water is lost by evaporation, seepage, runoff, or deep percolation

in soil. USDA estimates that only about 25 percent of the water currently withdrawn for irrigation is actually applied to crops and held in the root zone until used (28).

Of the 120 million acre-feet withdrawn for irrigation in 1960, only 94 million acre-feet was delivered to farms (13). The difference, about 26 million acre-feet of withdrawals, was lost by evaporation and seepage from reservoirs and canals. This loss could be reduced by lining reservoirs and canals, using pipelines, controlling water-wasting vegetation, and other measures.

Of water pumped on farms or received from irrigation canals, only about 47 percent on the average is made available to crops. By correct design and operation of the irrigation system, however, this level of efficiency can be raised to 70 to 75 percent (28).

The amount of water needed to irrigate a crop varies with the kind of crop, the location, climate, and current weather conditions, and many other factors. Seasonal water requirements for some crops in the West are as follows: Alfalfa, 22 to 52 inches; corn, 19 to 29 inches; cotton, 24 to 31 inches; grains, 12 to 18 inches; oranges, 18 to 32 inches; and pasture, 19 to 25 inches (4). The amount of effective rainfall at the location reduces the irrigation requirement accordingly.

Rice in Arkansas and Louisiana requires from 18 to 36 inches of water (2). Crops in humid areas need an average of about 6 inches of water to make up the deficiency in rainfall during dry periods in summer (11).

One of the most promising ways to conserve water in irrigation farming is to improve efficiency in irrigation designs and operations. In projecting agricultural water needs for the rest of the century, USDA estimated that feasible improvements in irrigation methods could provide enough water for needed expansion of irrigated acreage at least for the next 20 years (31). A projected 80 percent increase in land irrigated by the year 2000 can be supplied with only 20 percent increase in water withdrawals if conservation methods are widely adopted.

Need for irrigation water is not uniform throughout the year. Crops must be watered primarily during their season of growth, usually only a few months or even weeks. In humid areas, irrigation is needed only in dry periods during summer.

This concentration of need for irrigation water often puts a strain on local supplies even where the total quantity would be adequate if its use could be spread over the entire year.

Water for industry

Water is industry's No. 1 raw material.

Industrial use of water from private sources in 1950 averaged 77 billion gallons a day. By 1955 it had jumped to 110 billion gallons a day, and by 1960 to 140 billion gallons a day, including the 100 billion gallons a day used for fuel-electric power (13).

The Senate's Select Committee on supply and demand for water in the United States in 1960 predicted the 1980 use for industrial water at 363 billion gallons a day, an increase of 259 percent. It was further predicted that by the year 2000 use of water for industry in the United States would be as high as 662 billion gallons a day (37).

More than 95 percent of industrial water came from surface supplies in 1960, the rest from ground water.

In 1955 about 65 percent of industrial water was used by steam-generated electricity plants, mainly for condenser cooling (12). By 1960 this had increased to 71 percent. Altogether, about 94 percent of industrial water is used for cooling; the rest is used primarily for manufacturing and processing (13).

A few large plants use most of the water in manufacturing. Of 3,057 plants surveyed by the National Association of Manufacturers, 163 or 5.4 percent that used more than 10 million gallons a day each accounted for 78.2 percent of daily water intake (15).

Manufacturing uses tremendous volumes of water. As much as 300 pounds of water may be required for each pound of finished product (5).

The amount of water used for any product varies widely, according to the process used, efficiency of the plant, degree to which water is recirculated, and other factors. In table 4 are ranges reported by typical industries (15).

The trend toward synthetic and more highly refined products, as well as the rapid expansion of industry, calls for increased water supplies. For example, one company reports that making synthetic gasoline takes more than 15 million gallons of water per 1,000 barrels, compared to 1 million gallons of water per 1,000 barrels of refined aviation gasoline.

On the other hand, many plants can reduce their water intake by using other types of cooling systems or by recirculating and reusing water. For example, a carbon black plant in Texas with air-cooling uses only 0.25 gallon of water per pound of carbon black produced; similar water-cooled plants use 4 to 14 gallons per pound. By recirculating its water one oil-refining plant withdraws only 40 million gallons a day to meet a plant requirement of 600 million gallons a day.

TABLE 4.--Water used in manufacturing

Product	Water used, gallons
Steam-generated electricity, per M Kw.-hr.	52,000 to 170,000
Refined petroleum (processed crude), per M bbl.	151,000 to 15,000,000
Rayon yarn, per ton	250,000 to 403,974
Woolen cloth, per M yd.	40,000 to 510,000
Rolled steel, per ton	6,000 to 110,000
Paper and pulp, per ton	53,000 to 80,000
Paperboard, per ton	7,692 to 80,000
Cane sugar, per ton	4,000 to 27,920

Other especially low rates of water use reported by individual plants (9) include:

	Gallons
Steam-generated electricity, per M kw.-hr.	1,320
Refined petroleum, per M gal.	800
Finished steel, per ton	1,400

Local abundance or scarcity of water and the economics of installing and operating water-conserving equipment largely determine the practices used at each plant.

Availability of adequate water is a deciding factor in the location of new industrial plants. More and more, location of water supplies guides industrial development of the country.

Water for power

More water is withdrawn from streams and reservoirs to generate power than for all other uses combined. About 2,000 billion gallons of water a day was used for waterpower in 1960, 7-1/2 times as much as for all other purposes (13).

Most of this water is used to generate electricity. Some turns the machinery in small factories and mills.

Use of water for power increased 36 percent from 1950 to 1955, and an additional 33 percent from 1955 to 1960 (13). Many new hydroelectric plants are being constructed.

Although generation of power is considered a nonconsumptive use of water, evaporation from storage reservoirs is very large, estimated at 9 billion gallons a day in 1954. This is almost half the quantity of water withdrawn for all public supplies in the United States in 1960, and 2.5 times the quantity consumed.

Water for recreation and wildlife

Water is the key element in many kinds of recreation. It is indispensable to wildlife, which itself is valuable to recreation.

Water is neither withdrawn nor consumed for recreation and wildlife uses although some is lost to evaporation and seepage. But withdrawal and consumptive uses, such as irrigation and industry, often reduce the supply or diminish the value of water for recreation and wildlife.

These conflicts pose water problems of increasing importance as population grows and more people live in cities and have more leisure time.

Swimming, boating, fishing, and certain kinds of hunting that depend on suitable bodies of water are among the more popular recreational pursuits.

Intensive use of beaches, lakeshores, and parks and forests that contain streams and ponds shows the growing demand for recreation facilities. In 1955, 50 million people visited national parks and monuments--2-1/2 times the number of visitors in 1940 (16), and by 1960 these visitors had increased to 79 million. More than 46 million went to national forests for recreation in 1955, and 92-1/2 million in 1960. In 1960, 25 million people fished and 15 million hunted (29).

Supply and use of water for recreation and wildlife cannot be measured in gallons, as for withdrawal uses. Rather, availability and character of lakes, streams, and other bodies of water to meet the needs in each location are the crucial matters.

The Senate Select Committee on Water Resources (37) estimated that water losses in 1954 from water used by wildlife and fish amounted to 78 billion gallons a day from sport fish habitat, and 89 billion gallons a day from swamps and wetlands preferred by game waterfowl and other birds and animals. The figure for sport fish habitat was expected to increase to as high as 171 billion gallons a day by 1980 and 241 billion gallons a day by 2000. Losses from swamps and other wet areas, including fish hatcheries, were expected to decline to 66.7 billion gallons a day by 1980. After that, with provisions for increased habitat that probably would be demanded by a greatly increased population, water losses from these areas, largely from evaporation, should rise to 89.9 billion gallons a day by 2000.

Recreation water needs to be clean and in pleasant settings. It needs to be stable enough to avoid exposing mud flats or leaving boat docks stranded during the season of use.

Conflicts arise from uses that pollute streams, lakes, and coastal water; that dry up streams and lower lake levels; or that place obstructions like dams in the path of migrating fish.

Wildlife conservation, aside from recreation, involves other water problems. Fish, waterfowl, and many other kinds of wildlife require suitable aquatic habitats for propagation and survival. Destruction and contamination of these habitats by agriculture, industry, and other enterprises threaten the wildlife supply.

There are, for example, more than 74 million acres of water areas--marshes, sloughs, meadows, ponds, etc.--in the United States that are of value to waterfowl (21).

About 102 million acres have been drained in projects of 500 acres or more serving agriculture (26). How many acres are actually drained each year is not known, but some aquatic wildlife habitats inevitably are destroyed.

On the other hand, new reservoirs and ponds each year create water areas that produce fish and waterfowl. The constant extension of deltas and sedimentation along streams and in lakes adds to them. Some landowners are deliberately increasing marsh areas to produce wildlife.

An amendment to the Watershed Protection and Flood Prevention Act by Congress in 1962 authorized both financial and technical assistance to local groups

in developing watershed recreation. USDA can now help people of watersheds enlarge dams to form larger bodies of water, build new reservoirs specifically for recreation use, or improve natural lakes, streams, or shorelines, and pay costs of recreation facilities bordering water. The amendments are intended to help meet increasing public demand for water-based outdoor recreation facilities.

Other nonwithdrawal uses

Transportation of bulk freight by water is important to many industries and cities. During 1957, a total of 115 billion ton-miles of commercial traffic moved on inland waterways. This figure is increasing as channels are extended and improved. Since 1946, volume of freight has grown at an average rate of 7.8 billion ton-miles annually (34). The Corps of Engineers estimated for the Senate Select Committee on National Water Resources that water freight might be expected to double by 1980 and quadruple by 2000.

Streams also serve a valuable function in waste disposal. Within limits, they can purify organic wastes and dilute and carry away industrial refuse. Often, however, this use has turned to abuse. Growing cities and industries have overloaded streams with sewage and other wastes and created serious pollution of water supplies.

In estimating total national water requirements, the Senate Select Committee allocated 512 billion gallons a day as necessary minimum streamflow to dilute wastes under conditions existing in 1954 (37). Considering expected improvements in waste disposal, it projected this need at 332 billion gallons a day in 1980 and 446 billion gallons a day in 2000. In effect, this means a fourth to a third of the Nation's total streamflow must be dedicated to waste-dilution and is not available for consumptive uses.

SOURCES OF WATER

Despite growing water crises, there is no convincing evidence that total precipitation or runoff is either diminishing or increasing (39).

A city water shortage is a problem of demand--usually expanding rapidly--in relation to the local available supply, which may in fact be diminishing.

The Nation's water supply is not distributed evenly. Neither is its population, industries, or other water-consuming activities.

The water situation for the Nation may be seen in these totals, the result of the most recent studies of water supplies and their disposal by human activities:

Precipitation	4,300 billion gallons a day
Transpiration and evaporation	3,100 " " "
Total streamflow	1,200 " " "
Streamflow available 90 percent of the time	130 billion gallons a day
Withdrawn from sources for use by humans (1960)	270 " " "
Consumed (1960) in use by human activities	61 " " "

Precipitation ranges from more than 150 inches annually at places along the Northwest coast to less than 5 inches in parts of the arid Southwest. As shown in map 1, it varies widely.

Annual runoff--a better measure of the water readily available--varies even more widely (map 2). It is more than half the precipitation in some humid areas, but less than 5 percent of the scanty rainfall in some arid ones (32).

In most places both precipitation and runoff also vary greatly from month to month. Unless some of the water can be stored in the flush season to be used in the dry, most communities face water scarcity at intervals.

Surface water

Rivers, creeks, lakes, and reservoirs are the major source of available water. They supply nearly 70 percent of the water used by cities and towns and by farmers for irrigation, 80 percent of the fresh water used for industry, and nearly all of that used for hydroelectric power (13).

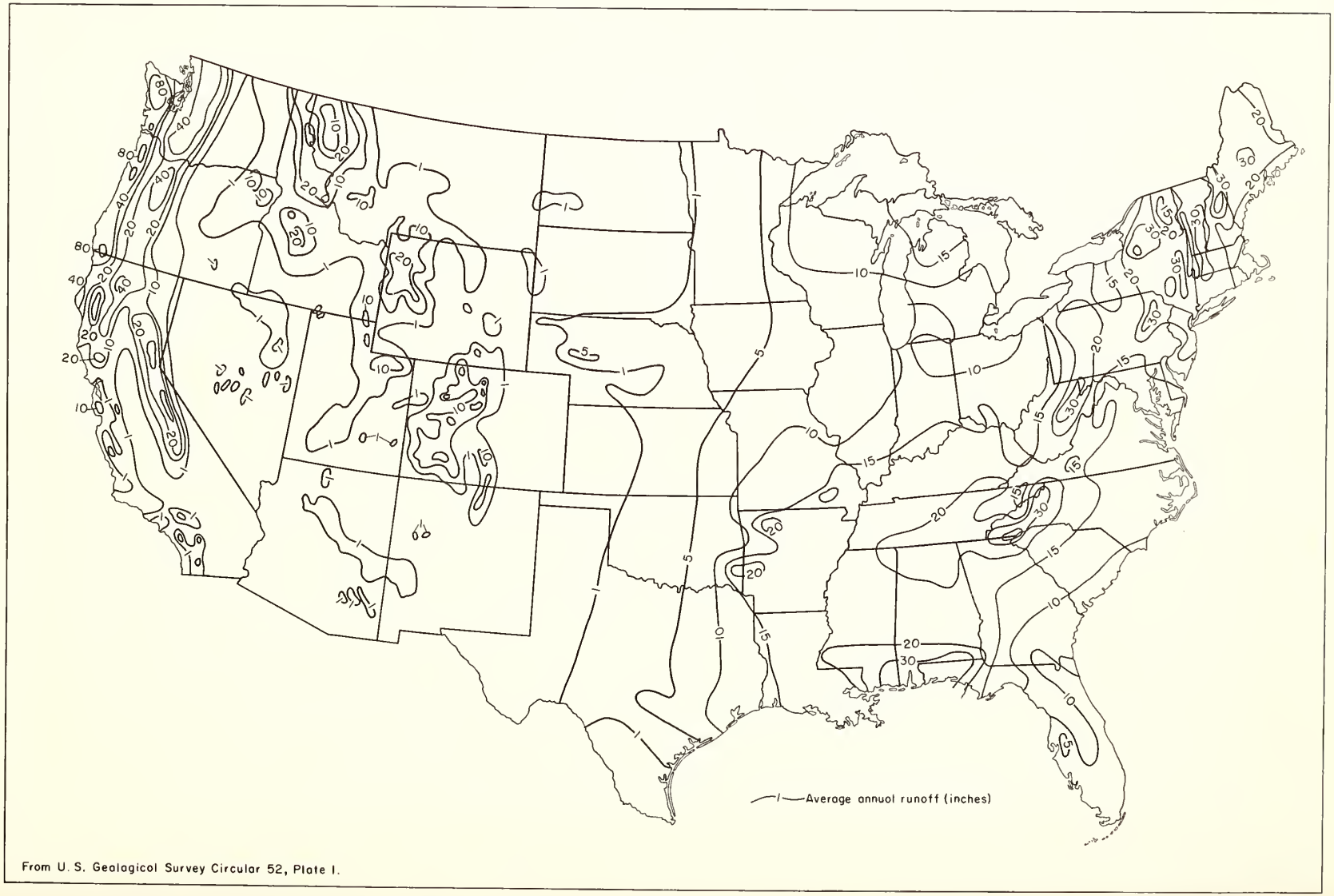
During the 5-year period 1955-60, use of surface water, exclusive of that for waterpower, increased from 190 to 220 billion gallons a day, or 16 percent; use of ground water increased from 46 to 47 billion gallons a day, or 2 percent (13).

Streams.--Land use has greatly changed the flow regimen of many streams. Deforestation, urbanization, bad farming practices, and range abuse decrease insoak during rains. More of the water runs off quickly, causing increased flooding; less enters the ground to sustain plant growth, feed springs, and contribute to streamflow.

Soil Conservation Service, Forest Service, Agricultural Research Service, and Tennessee Valley Authority have recorded such changes in several watersheds. For example, during the rains that caused the Kansas River flood in 1951, peak runoff from one small farmland watershed near Hastings, Nebr., was twice as great and occurred in half the time as runoff from an adjoining watershed where conservation practices were in effect (3).

A small watershed converted to farmland at the Coweeta Hydrologic Laboratory in North Carolina had roughly four times as much surface runoff during a particular storm as it had from a similar storm before its forest cover was cleared (10).

Land use changes and cover improvement reduced flood peaks and sedimentation rates on two



From U. S. Geological Survey Circular 52, Plate 1.

UNITED STATES
DEPARTMENT OF COMMERCE
WEATHER BUREAU

MEAN ANNUAL TOTAL PRECIPITATION (Inches)

SHEET OF THE NATIONAL ATLAS
OF THE
UNITED STATES

Base map by United States Weather Bureau
Subject data based on 3515 station records, 1931-55
Prepared by Office of Climatology

SCALE 1:10,000,000
ALBERS EQUAL AREA PROJECTION STANDARD PARALLELS 29½° AND 45½°

EDITION OF 1960
MEAN ANNUAL TOTAL PRECIPITATION (Inches)
LIBRARY OF CONGRESS G3701 C90
DEWEY DECIMAL 551.57300973

watersheds in Tennessee without materially affecting water yields or total evapotranspiration (6).

USDA and other Federal and State agencies are cooperating in making surveys of many of the Nation's river basins. Leadership of USDA's participation in the surveys has been assigned to the Soil Conservation Service. Authority for the cooperative investigations and surveys is found in the Watershed Protection and Flood Prevention Act.

A river basin survey is intended to determine a pattern for development and use of the water and related land resources of the basin for flood prevention, agricultural, recreation, fish and wildlife, and municipal and industrial water supply purposes.

River basin surveys take into account the water and related land-resource projects functioning in the basin. Basin reports point out how additional structural measures and soil conservation practices on land can contribute to conservation and use of water and land resources.

Natural lakes.--The amount of water stored in natural lakes is large compared with that in streams, but most of it is not available for uses that require withdrawal. Natural lakes, except for the Great Lakes, are better known for their recreation advantages than for other contributions to the national economy.

Reservoirs.--On the other hand, reservoirs are so constructed that they have little dead storage; the water is above the lowest outlet and can be released when needed.

Without this artificial storage, less than half the runoff in humid areas can be depended upon for regular use. In arid and semiarid areas even less can be beneficially used. Loss of water by evaporation is counted as one of the costs of storing water.

In 1954 there were 1,300 reservoirs larger than 5,000 acre-feet capacity, with a combined surface area of more than 11 million acres. These larger reservoirs could store 278 million acre-feet of water--more than 20 percent of the annual streamflow (24).

In addition there are countless smaller artificial lakes and ponds. The Soil Conservation Service records show that farmers and ranchers have built more than 1-1/4 million. The average size of these is about 2 acre-feet.

Ground water

Underground reservoirs contain more fresh water than all surface reservoirs and lakes combined, including the Great Lakes. Ground water is estimated to equal 10 years' average rainfall or 35 years' average runoff (18).

This water has accumulated through the centuries. Only a small part of it is available for human use. Nevertheless, about one-sixth of all the water used in the United States comes from underground sources.

Ground water is part of the water cycle. Water that soakes into the ground beyond the plant-root zone adds to underground water. Most underground water moves, though often very slowly, and some is discharged as springs and seeps or subsurface flow in streams.

Variable rock structure causes underground water to be very unevenly distributed. In less than half the United States can wells be made to yield enough water for irrigation, industrial, or municipal use. The U.S. Geological Survey has mapped the principal ground water reservoirs of the United States (22, 23).

In many areas ground water is being used faster than it is naturally replenished through the water cycle. Water levels in wells are dropping; irrigation projects, municipalities, and industries depending on them are threatened.

For example, in the southern High Plains, the rate of pumping in the early 1950's was 30 to 50 times the estimated recharge. In the Chicago area pumping for city water supply had lowered artesian pressure by more than 400 feet (22).

In many coastal areas salt water is replacing fresh water where overpumping has lowered water tables to below sea level. In some oil fields salt water from lower levels often contaminates fresh-water supplies. Many of the States are attempting to solve this problem by regulating oil field operations. These and other types of salt-water intrusion are making serious inroads on useful ground-water supplies (17).

WATER LOSSES

Local water shortages arise in part from losses that keep some of the potential supply from being put to beneficial use.

Flash runoff robs communities of part of their natural water resource. Peak flows that exceed storage facilities are an economic loss, aside from the damage they do as floods.

Sedimentation that reduces storage capacity, evaporation that dissipates stored water, and pollution that makes water unfit for certain uses all reduce the usable supply.

Sedimentation

Transported eroded materials deposited as "sediment" create downstream damages to waterways and water-storage facilities. Each year this deposition in natural and artificial channels and in reservoirs and harbors adds up to tremendous losses in both water supplies and water qualities.

Fortunately the study of sedimentation and ways to prevent it has expanded in the United States since World War II. In 1946 sediment load measurements were being made at less than 300 measuring stations, mostly with makeshift equipment. In 1960, such measurements were made at over 800 stations using standard samplers and sampling procedures. Also, locations of stations now give a better representation of the different physiographic areas of the country.

Reservoir sedimentation surveys had been made on more than 1,000 reservoirs in the United States by 1963. At that time SCS estimated the average annual loss of capacity to the Nation's major reservoirs by sedimentation at 850,000 acre-feet.

Reservoirs lose most of their value when they are 50 to 60 percent silted. Their useful life, therefore, may be as little as 15 to 20 years where sedimentation rates are high and storage capacity is small, as with farm ponds receiving runoff from unprotected cultivated land.

On the other hand, large reservoirs in forested areas or with otherwise well-protected watersheds may be useful for 200 to 300 years or more if they remain protected.

Sedimentation damages are costly. In a study of 22 southeastern cities, it was found that the cost of water treatment amounted to about $70 per million gallons for plant, equipment, and actual water treatment to make the water usable (7).

An analysis of 157 watershed work plans covering a total combined drainage area of 9.7 million acres shows interesting results regarding sediment sources. The study indicates that 73 percent of the sediment is derived from sheet erosion, 10 percent from gully erosion and 17 percent from other sources such as roadside erosion, streambank erosion, flood-plain scour, etc. The rate of erosion, before conservation treatments had been applied in the watersheds, amounted to about 78 million tons of sediment a year. The watershed projects, when completed, will reduce this erosion by about 47 percent (8).

Evaporation and transpiration

Evaporation from surface reservoirs is a loss that cannot be avoided, but sometimes might be reduced.

Normal evaporation from the 11-million-acre surface of the Nation's major reservoirs equals the quantity of water withdrawn for public use (13). Evaporation from farm ponds is more than the water used for rural homes and livestock (12).

Evaporation from reservoirs can be held to a minimum by good design that results in small surface area in relation to storage capacity. Tree and shrub windbreaks sometimes can reduce evaporation from small ponds. Experiments with chemicals that form a thin film on the water surface offer hope of another way to reduce evaporation (30).

Transpiration from crops, forests, range, and wildlife and watershed cover is perhaps the most important use of water. But transpiration from plants that grow with their roots in the water table, called phreatophytes, withdraws much water from reservoirs, streams, and irrigation canals. These plants occupy an estimated 16 million acres in the West. They consume 20 to 25 billion gallons of water a day (33). If such plants are removed from some sites, other plant cover or some other type of protection may be needed to prevent erosion.

Pollution

Pollution of streams, lakes, and coastal waters with sewage and other wastes from cities and industries reduces the supply of water suitable for many uses.

A study of sewage flows reported in 1960 (36) estimated flow and discharge from the Nation's sewage systems, with projections into the future, as follows:

16.7 billion gallons a day in 1954
28.6 " " " " " 1980
42.5 " " " " " 2000

The report stated that our waters were receiving twice as much pollution from municipal sewage systems alone as was considered allowable in 1955. Pollution of waters by sewage is so closely related to urban population that the more recent studies of the problem are based on population growth and redistribution throughout the country. Estimates revealed that the larger metropolitan areas will contain 70 percent of the total population by 1980 and 80 percent by the year 2000. Moreover, it is estimated that by then 95 percent of the population will live in places that are equipped with sewage systems.

Municipal sewage is composed of domestic, commercial, and public wastes, and industrial wastes discharged through municipal sewage systems. In 1960, it was estimated that about 80 percent of industrial establishments were connected to municipal systems.

New types of wastes that cause new problems in connection with water supplies are synthetic organic chemicals, radioactive substances, newly identified viruses, and disease-producing micro-organisms.

Also, detergents, pesticides, and herbicides that reach the streams and underground waters from land surfaces present a problem the magnitude of which is not yet known. Research to determine the effects of such materials on water supplies is being carried out in many areas. There now are more than 100 synthetic organic insecticides on the market and these are available in thousands of different formulations. Studies are also in progress to develop control methods that would reverse the trend of widespread use of insecticides and pesticides (36).

Although cities and industries return most of the water they use to natural sources, much of the water may be worthless for reuse.

Pollution from sewage can be controlled. Several States have pollution-abatement programs that have made dramatic improvements in important rivers. Amendments to the Federal Water Pollution Control Act of 1948, enacted in 1956 (Public Law 660, 84th Cong.), broadened the role of the Federal Government in assisting the States to carry on and coordinate their pollution control programs. The law as amended provides for both financial and technical assistance to States, groups, and individuals

in preventing pollution of waters, enforcing measures against pollution of interstate waters, and carrying on research, investigations, training, and information programs relating to the causes, control, and prevention of water pollution.

Sediments from surface runoff have an important bearing on water quality. Costly treatments are necessary in many areas to purify muddy water, and sediments often must be removed from waters where fish and shellfish populations are needed. It is estimated that the suspended-solids loadings reaching the Nation's streams by way of surface runoff is at least 700 times the loadings caused by sewage discharges.

Future sediment problems and solutions are very important from the point of view of pollution control. The building of detention and impoundment dams in watershed projects will give clearer waters and affect beneficially the physical, chemical, and biological factors involved in the assimilation by the water bodies of wastes from sewage.

PROBLEMS OF TOO MUCH WATER

Too much water at the wrong time may be as serious as too little. Many communities must cope with recurring floods. Much good land is too wet for agricultural use without drainage.

Floods

Hardly a year goes by without a disastrous flood somewhere in the United States.

Less spectacular are the many floods that occur every year on the smaller tributaries of the great rivers. These smaller floods cause even more total damage than the big ones.

The average annual damage from floods in the United States is about $1 billion, about equally distributed between the upstream tributaries and downstream valleys.

Most of the damage on the headwater streams results from floods that occur oftener than once in 10 years. Most of this damage--about 70 percent--is agricultural.

Most of the downstream flood damage is to residences, industrial property, and transportation facilities. These damages continue to rise from year to year because of increasing value of property concentrated in flood plains. Even so, about a third of the damage in large valleys is to rich agricultural land in flood plains.

Floods can be reduced by soil and water conservation on the farmlands, forests, and ranges that make up the watersheds, and by water-control structures on the upstream channels.

Floods can be further controlled by large downstream dams, dikes, and other structures to protect cities and towns, urban property, and agricultural land on the downstream flood plains.

Both upstream and downstream measures are encouraged by the Federal Government.

Drainage

Drainage of wet land has been a step in much of the settlement and agricultural development of America.

Nearly a fourth of the Nation's potential agricultural land, or about 216 million acres, was originally too wet for farming (1).

Even urban development has depended upon drainage. Many town sites in the eastern and coastal areas had to be drained. Central Park in New York City was drained in 1858.

The 1960 Agricultural Census showed nearly 102 million acres in organized drainage enterprises (26), of which about 92 million acres have been improved. This included extensive areas of flat fertile land in the humid States that proved to be among our most productive cropland. These Census figures are exclusive of projects benefiting less than 500 acres and land in irrigation enterprises which is covered by the irrigation census.

The National Inventory of Soil and Water Conservation Needs confirmed the widespread urgency for improved drainage on cropland to maintain farm efficiency. Of the 55 million acres in the 48 mainland States where excess water was the dominant problem, 33 million acres of cropland needed drainage. The inventory also showed that drainage of cropland was needed in 12 million additional acres where excess water was the secondary conservation problem, with erosion, unfavorable soil conditions, or adverse climate being classed as dominant problems.

Other land was found to need drainage besides cropland. Control of excess water was the dominant problem on 11 million acres of pasture land. The inventory revealed that 98 million acres of woodland and forest were on wet soils and excess water was the major conservation problem on 16 million acres of other miscellaneous land. Substantial areas of these, especially the wet woodlands, may be classed as a national reserve asset because they can be drained and placed under cultivation if the need for more cropland arises in the future.

In times of crop surpluses the question is sometimes asked as to justification for draining land. This is an important problem in considering new projects. Present policies exercise a strict control over government assistance in bringing new land into cultivation.

On the other hand, removal of excess water from the 33 million acres of cropland now needing drainage is primarily a matter of farm efficiency. It is impractical to farm wet land. Therefore, if land is to remain in cultivation it must be drained so the farm can be operated as an economic unit.

Of high priority is the drainage of at least 4 million acres of cropland in irrigated projects. Such projects are developed at high cost. Excess water contributes to salinity and alkali problems. The usefulness of land may be destroyed at least for this generation by the encroachment of saline and alkali salts.

The conservation needs studies and surveys found that the total farm drainage problem throughout the 48 mainland States includes about 172 million acres. A total of 3,931 drainage projects are needed to remove excess water from 45 million acres. Some 549,000 farms would benefit.

Much of the land needing drainage for agriculture is not covered with water. Rather, the soils are waterlogged, excluding air from the root zone and making them unsuitable for growing crops. Or they may be dotted after rains with transitory pools that interfere with land preparation and planting or that drown out patches of crops, then disappear.

Of the 74 million acres of wetlands inventoried by the Fish and Wildlife Service in 1954, 35 million or nearly one-half were subject to only seasonal flooding (21).

Naturally, the best and most easily improved land was drained first. Nevertheless, some land drained for agricultural purposes was later found to be unsuitable for crop or pasture production.

New drainage work needs to be carefully planned within the known capability of the land. Wildlife and recreation values also need to be safeguarded.

WATERSHED PROTECTION AND CONSERVATION

Water problems, in the last analysis, are watershed problems. A watershed is any area of land that drains into a particular stream or body of water. Small streams, of course, flow into larger ones, so the entire country is a patchwork of small watersheds making successively larger ones.

Watershed divides separate the water supply into distinct parts as it comes to us in the water cycle. The character and condition of the land on which water falls influence its movement into or over the ground. Land management, therefore, affects the timing of the water's arrival to streams, lakes, or underground reservoirs from which it can be withdrawn for human use.

People in each watershed have their own water resource with which to meet their own needs. It is within these confines that problems of water shortage, flooding, or pollution arise.

And it is within separate watersheds that communities can manage their water resource to best meet their own needs.

Small watershed projects

Solution of water problems in a watershed takes teamwork.

All the people must plan and act together to make best use of all their land and water resources.

Water control and conservation cannot be separated from soil conservation. Since urban and industrial uses also make demands on water supply and affect its quality, city people as well as farmers must take part in watershed projects.

Farmers across the Nation are attacking water problems where they begin--on land. Soil conservation districts include nearly 95 percent of all agricultural land. Through these locally managed districts, individual land owners and operators are putting basic soil and water conservation plans into effect on their own land.

At the same time, rural and urban interests all over the country are joining forces in small watershed protection and flood prevention projects that deal with all aspects of land and water conservation.

This teamwork on the part of local people is matched by teamwork among governmental units. Local, State, and Federal agencies cooperate in planning, financing, and carrying out projects under the Watershed Protection and Flood Prevention Act (Public Law 566, 83rd Cong., as amended). More than 2,268 groups of citizens had applied for Federal financial and technical assistance in planning and carrying out watershed projects by April 1965.

These projects combine soil and water conservation on the land with control and use of runoff by means of upstream dams and other structures in small watersheds. Land treatment to increase vegetation, improve soil condition, and retard surface runoff precedes structural work on the streams.

The Federal Government, through the U.S. Department of Agriculture, provides three kinds of assistance to local organizations in planning and carrying out small watershed projects: (1) Technical assistance for planning, installing, operating, and maintaining works of improvement; (2) financial assistance to defray all of the cost for structural measures for flood prevention and part of the cost for irrigation and drainage and for fish and wildlife development and recreation, including acquisition of land easements or rights-of-way for public recreation or fish and wildlife development; and (3) long-term credit to help local interests finance their share of the costs, including the full cost of municipal or industrial water supply.

Most small watersheds offer excellent opportunities for multiple-use developments for combining several purposes in single developments. Towns and cities have an added incentive for capitalizing on the well-known savings even though they have no immediate need for more water. Loans for future water supply are available without interest for as long as 10 years after the reservoir is built.

Small watershed projects are started by local organizations such as soil conservation districts, municipalities, counties, watershed districts, or irrigation companies.

Soil Conservation Service has administrative leadership for USDA's part in these projects. Upon request SCS will supply information about the Watershed Protection and Flood Prevention Act and the benefits it authorizes. Loans are available from the Farmers Home Administration of USDA.

In small watershed projects, the activities of all agencies dealing with water control and management

can be correlated. These might include downstream flood-control work by the Corps of Engineers, reservoirs and irrigation projects by the Bureau of Reclamation, wildlife-habitat development by the Fish and Wildlife Service, pollution abatement by the Public Health Service, and development of municipal and industrial water supplies.

WATER RIGHTS

In pioneer days supply exceeded need for water in the humid East. A person's right to use water where he found it was taken for granted, like his right to breathe the air. Water uses at that time were primarily for domestic, navigation, and other "in the stream" activities.

As more people sought to make use of streams, conflicts sometimes arose and were settled by courts in accordance with common-law doctrine of riparian rights.

This doctrine emphasizes the riparian principle that owners of land touching the same stream have equal rights to make reasonable use of it, each being subject to rights of other owners--the share-and-share alike ideal.

In the arid West, on the other hand, miners and settlers from the first competed for the limited water supply. They established the principle that the water user "first in time is first in right." This became recognized by the territorial courts, and later became part of the legislative acts providing for appropriation of water for beneficial use under supervision of a State water agency.

Now, in all States, needs for water have increased and competition raises many questions of water rights.

When a farmer uses a stream to irrigate, a city builds a dam for water storage, or a county diverts runoff to protect a county road, legal questions may be raised relating to rights to use, store, or divert the water, for liability for damages, or for both. In general, any activity connected with storing, retarding, diverting, discharging, collecting, pumping, or otherwise affecting flow or use of water could infringe upon rights of use or result in damage to property of others. Many eastern States and some of the western ones, therefore, are taking steps to study their water problems and to modernize their water laws in accordance with sound principles of water use in the national interest.

In small-watershed projects, in assisting soil conservation districts, and in all other projects and activities, USDA requires appropriate conformance with provisions of State water laws. The landowners, the sponsoring local organizations, and other local people concerned in each project are responsible for obtaining the necessary water rights and construction permits.

SOME MEASURES OF WATER

1 gallon is 231 cubic inches, 0.1337 cubic feet.
1 cubic foot is 7.48 gallons.
1 gallon weighs 8.34 pounds.
1 cubic foot weighs 62.4 pounds.
1 acre-inch is 27,154 gallons or 3,630 cubic feet.
1 acre-foot is 325,851 gallons or 43,560 cubic feet.
1 cubic foot per second is 448.8 gallons per minute or 646,317 gallons per day.
1,000 acre-feet per year is 0.893 million gallons per day.

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